File Nordheim 44-1-61

Date 1/5/44

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Subject CONSIDERATION ON THE POWER OUTPUT IN THE X ~~XXXXXX~~ PILE

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January 5, 1944

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Considerations on the Power Output in the X - Pile

Abstract

Estimates are discussed of the possible gain in power output in the X Pile by increasing the amount of metal in the pile together with a poisoning of its central part. Addition of about 12 tons of metal would bring a net gain in power output by 40 percent without interfering in any way with the operation of the pile of the separation plant.

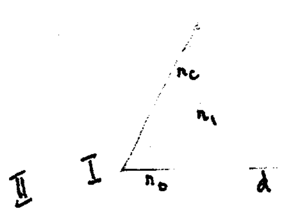
The power output of the X pile is limited at present by the admissible temperature of the hottest slug. It is unlikely that any other limiting factors, like too high temperature gradients through the shield, will enter before the output is raised to 2000 KW or more.

In view of this situation, the only practical method of increasing the output, i.e. the production, without radical change of equipment, consists in increasing the amount of metal in the pile. The gains that can be achieved in this way are twofold. Firstly, the larger amount of metal entails obviously a proportionate increase in production when the neutron density is kept constant. Secondly, with a larger amount of metal, the neutron distribution in the pile can be flattened out by poisoning the central part of the pile, so as to lower the ratio of maximum to average intensity.

It is the purpose of this memorandum to estimate the possible gains by this method and to determine the poisoning requirements.

I. Flattening of the Pile

Optimal utilization of a given amount of material is achieved by reducing k in the center region of the pile to unity, which gives a constant neutron density n. The outer layer should be operated at optimal conditions in order to effect the most rapid decrease of n towards the edge of the pile. From a practical point of view, however, a cylindrical arrangement is simpler to handle than a spherical one. We treat therefore the former case, in which the central region is flattened out only in the radial direction.



We denote by r_0 the radius of the inner section

r_1 = the radius of the active pile

r_c = r_1 + d = radius of pile including reflector correction (d = 45 cm)

h = the length of the pile

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It is assumed that a carbon reflector is left at the front, but not at the rear end of the pile.

The neutron distribution is then given by

$$n = n_o \cos \frac{\pi}{h+d} z \quad \text{for} \quad r < r_o \qquad (1a)$$

$$n = n_o \quad \frac{K_o(\varkappa r_e)\, I_o(\varkappa r) - I_o(\varkappa r_e)\, K_o(\varkappa r)}{K_o(\varkappa r_e)\, I_o(\varkappa r_o) - I_o(\varkappa r_e)\, K_o(\varkappa r_o)} \cos \frac{\pi}{h+d} z \ \text{for} \ r \quad r_o \qquad (1b)$$

where I_o and K_o are the cylinder functions of order zero and

$$\varkappa = \sqrt{|\Delta| - \left(\frac{\pi}{h+d}\right)^2} \qquad (2)$$

where Δ is the Laplacian of the normal pile ($\Delta = 104 \times 10^{-6}\ cm^{-2}$)

The radii have to fulfill the relation

$$\frac{K_1(\varkappa r_o)}{I_1(\varkappa r_o)} = \frac{K_o(\varkappa r_e)}{I_o(\varkappa r_e)} \qquad (3)$$

This relation can be used to determine r_o for any given amount and arrangement of metal. The ratio of average neutron density n_{Av} over the maximal density n_o is given by

$$\frac{n_{Av}}{n_o} = \frac{h+d}{\pi r_1^2 h}\left(1 + \cos\frac{\pi d}{h+d}\right)\left[r_o^2 + \frac{2r_1}{\varkappa}\,\frac{K_o(\varkappa r_e) I_1(\varkappa r_1) - I_o(\varkappa r_e)\, K_1(\varkappa r_1)}{K_o(\varkappa r_e) I_o(\varkappa r_o) - I_o(\varkappa r_e)\, K_o(\varkappa r_o)}\right] \qquad (4)$$

The following table gives representative results for a number of distributions.

TABLE I

Ratio n_o/n_{Av} of maximum to average neutron density for various amounts and arrangements of metal in X pile.

	Present	Minimum loading	Present amount shortened			
Amount of metal in pile (tons)	35.7	27.7	35.7	48	48	75
Number of slugs per channel	65(30)	47	47	65	50	65
Number of stringers in central portion	0	0	45	106	144	339
Total number of stringers	400 (60)	460	591	575	750	992
Ratio n_o/n_{Av}	2.6	2.6	2.2	2.15	2.0	1.95
Output compared to present output for same temperature of hottest slug	1	0.75	1.18	1.60	1.75	2.6

II. Utilization of Flattening

The figures in the last row of Table I give directly the gain compared to the present loading for the case that the air flow through the channel is kept constant. This would be the case if the unused channels are partially filled with graphite triangles so as to compensate for the difference in air flow by removal of the slugs. We see that an addition of about 12 tons of metal gives a gain of around 60% in this case. A further slight gain would be achieved by shortening the active length of the pile while increasing its radius, which leads to a more favorable shape. The maximum possible gain achieved by filling the whole pile with metal (except for two layers of holes at the outside to provide for a reflector) is shown in the last column of Table I.

In case the unused holes are plugged up, the gain will be somewhat lower than indicated by Table I, since the air flow per channel will be the larger, the smaller the number of channels. An estimate of this reduction can be made with the help of the data in MUC-CMC-147 for the case that the unused plugs are completely sealed and that no leaks for the air flow exist. For a slug temperature of 150° C and an outlet air temperature of 70 to 75° C (inlet at 0° C), the following values are found.

TABLE II

Reduction in Power Output due to Decrease of Air Flow at Increase of Number of Open Channels

Number of openings	460	575	750	992
Δp across pile ("H_2O)	19	16	13	9
Flow per channel (CFM)	63	58	51	43
Total air flow through pile (CFM)	29000	33500	37000	43000
Reduction compared to present case	1	0.93	0.83	0.71

The reduction will not be quite as large as indicated in Table II, if the plugs do not give a complete seal for the unused tubes or in the presence of leakages.

It is seen from the figures of Tables I and II, that the addition of 12 tons of metal will give a total gain in output between 40 and 50 percent, at the same slug temperatures as at present and without any change in equipment. The slight gains in the ratio nW/n_e obtained by shortening of the pile are, however, compensated by a reduction in cooling efficiency so that this procedure does not give an improvement.

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It should be pointed out that the addition of more metal will not reduce the concentration of product in the pile or overtax the separation plant. At a fixed rate of removal of slugs for product extraction, the additional metal will simply remain in the pile for a longer period and will actually accumulate a higher concentration of product than at present.

III. Poisoning Requirements

The amount of poisoning material per channel is independent of the amount of metal in the pile so that the adding of new metal can be done gradually.

The Laplacian in the central region will be

$$|\Delta| = \left(\frac{\pi}{h + d}\right)^2 = 18.5 \times 10^{-6}$$

corresponding to a

$$k_0 = 1 + \Delta M^2 = 1.014$$

The required change in k will be then

$$\frac{\Delta k}{k} = \frac{k - k_0}{k} = 0.006$$

This change would require approximately 6.7/D gram per cm length of absorbing material with danger coefficient D, i.e. around 5 gm of Iron or 5.7 gm of Thorium or 0.3 gm of Silver per cm length of channel. The most practicable way for producing such an effect would be the insertion of a suitable wire (for instance of boron steel) in the channels or the introduction of spacers made of the poisoning material between the Uranium slugs. A third method would be to use uranium slugs which are partially depleted of U^{235}. This method would provide an excellent utilisation of such material in case considerable amounts of it became available.

LWN:s

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